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CONTRIBUTIONS FROM THE JEFFERSON PHYSICAL LABORATORY, HARVARD COLLEGE.

# *ON THE PERMEABILITY AND THE RETENTIVENESS OF A MASS OF FINE IRON PARTICLES.*

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# ON THE PERMEABILITY AND THE RETENTIVENESS OF A MASS OF FINE IRON PARTICLES.

By B. Osgood Peirce.

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In a familiar lecture-room experiment, a mass of iron filings, filling a straight glass tube to a length of thirty or forty times its diameter, is forced to become a rather weak "bar magnet" by subjecting it to a strong exciting field in a solenoid; and then, by rearranging the particles, it is made to lose its magnetic moment almost completely, although, if, after the filings have been poured out of the tube, a few of them be examined under a microscope of moderate power, it is usually easy to see that most of the elongated particles retain some magnetism for a good while. A number of persons [1] have studied the magnetic properties of masses of iron filings or of chemically deposited "iron dust," as well as of mixtures of iron particles in various proportions with non-magnetic powders of various kinds. Concise statements of the results of experiments on the subject are to be found in the papers of Maurain and Trenkle.

I have lately had occasion to measure the permeability and the retentiveness of each of several masses of very fine cast-iron particles, or dust, made by a fine cutting end-mill in a milling-machine, and, as testing the effect upon their magnetic properties of subjecting the particles to a "hardening" process, the results seem to have some slight interest.

The material to be examined was tamped solidly into a glass tube almost exactly one centimeter in diameter, until a column was formed fifty diameters long. After its ends had been closed by corks, the comparatively short tube was put into the middle of a long solenoid $S$, the

[1] Töpler, Pogg. Ann. d. Phys., 1877; v. Waltenhofen, Wied. Ann. d. Phys., 1870; Jamin, Comptes rendus, 1875; Börnstein, Pogg. Ann. d. Phys., 1875; Auerbach, Wied. Ann. d. Phys., 1880; Baur, Wied. Ann. d. Phys., 1880; Maurain, Éclairage, Élect., 1903; Trenkle, Erlangen. Sitzungsberichte, 1905; Wied. Ann. d. Phys., 1906.

axis of which was horizontal and perpendicular to the meridian. The connections of the apparatus are shown schematically in Figure 1.

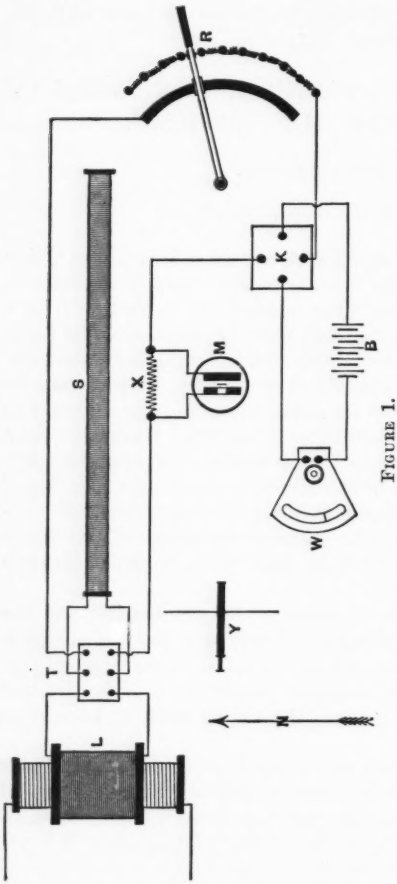


FIGURE 1.

After the tube ($Q$) had been placed in $S$, the double switch $T$ was closed to the left, so as to connect $S$ with the secondary ($L$) of a transformer the primary of which was attached to the alternating street circuit. The secondary coil was so suspended with counterbalancing weights in a tall frame that it could be moved at will in the direction of its axis to a distance of several feet away from the primary, and thus a great number of alternations of a current gradually decreasing in intensity could be sent through $S$ to demagnetize the specimen in it.

$M$ represents a magnetometer in the form of a mirror galvanometer placed in Gauss's B Position with respect to $Q$; the galvanometer was so shunted by an adjustable resistance $X$ that the effect on the galvanometer needle of the partial current through the coils of the instrument almost exactly compensated for the effect of the whole current through the solenoid $S$ when empty. $R$ is an adjustable rheostat of 200 ohms total resistance, designed to carry currents of some intensity, $K$ is a commutator, and $W$ a milliamperemeter furnished with a set of

four shunts. When the switch $T$ was closed to the right, it was possible, by manipulating the rheostat arm and the commutator $K$, to put $Q$ through any desired hysteresis cycle in the usual manner. The current came from a battery of storage cells, any number of which could be used at pleasure. A current of 1 ampere in the solenoid gave rise to a field of 54.8 gausses in the space within it. The field about $M$'s needle had to be artificially strengthened to suit the circumstances, and a piece of soft Bessemer steel rod of almost exactly the same dimensions as the column of filings was used to determine the sensitiveness of the apparatus at any time. By means of a coil of 20 turns of extremely fine insulated copper wire wound directly on this piece at its centre and connected with a carefully standardized ballistic galvanometer, the induction flux through the centre of the rod could be found and the corresponding deflection of the magnetometer needle determined.

The work was undertaken in order to compare the magnetic properties of masses of iron particles, as they came from the milling-machine, with those of masses of particles from the same lot which had undergone the treatment used in hardening iron castings for permanent magnets. These "filings" were prepared by Mr. G. W. Thompson, the mechanician of the Jefferson Laboratory, who has had much experience in the process. A completely closed iron crucible with thin walls, containing a mass of the particles to be treated, was heated white hot under a power blast in a gas furnace, and then suddenly chilled in an acid bath. After this experience, during which the particles had been carefully excluded from the air, they had a somewhat altered color and lustre, but under a microscope of low power showed very little difference from the untreated particles; at best all such particles cut by machine tools from iron castings are most irregular in form, and are so much seamed by deep furrows and pits as to look like clinkers from a furnace. All the particles were kept quite free from oil or dirt, and the surfaces of the "hardened" ones were only very slightly tarnished, but it was not possible to pack quite so large a mass of the material into a given space after the treatment as before. This might have arisen from changes of shape, but it is a suspicious fact that the induction flux through the centre of a column (of given dimensions) of the filings under a given excitation was almost exactly the same whether the filings had heen hardened or not. Two uniform glass tubes from the same piece and practically of the same dimensions were filled respectively with 103 grams of untreated particles and 96 grams of the others, and each was put several times through a hysteresis cycle, using about 250 gausses as the intensity of the maxi-

mum exciting field. After this 22 simultaneous determinations of $H$ and $B$ were made in each half-cycle, and both cycles were carefully plotted on such a scale that each was about 40 centimeters long. It appeared that the maximum values of the induction were almost identical, and that at no point were the plotted curves so much as 1 millimeter apart. In filling the same glass tube a number of times in succession from the same lot of filings, it was of course impossible to pack exactly the same mass into the same space twice; but the hysteresis diagrams,

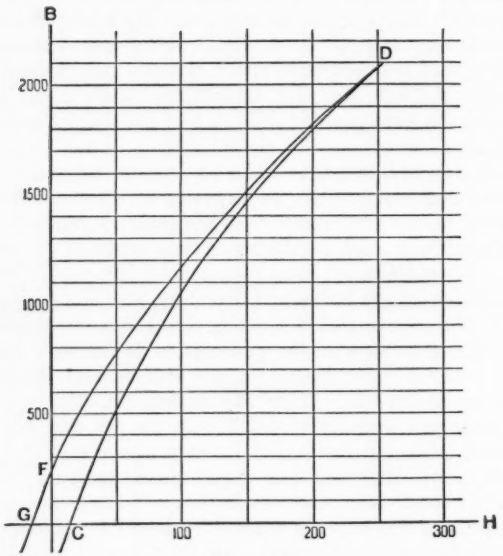


FIGURE 2.

many of which were obtained by Mr. J. Coulson and myself, were always of the same shape, and the intensity of magnetization due to a given exciting field seemed to be strictly proportional to the mass. The density of the untreated filings was only about four tenths of that of massive cast iron.

The demagnetizing effect of the ends in a rod of solid iron only fifty diameters long would of course be very serious, but in the present case, due to the relatively small value of $I$ for a given value of $H$, it is far less important. In order to determine from my observations the permeability at the centre of an endless column of material like

mine, I have used the value of $N$ computed by Du Bois[2] from the experimental results of Ewing, Tanakadaté, and himself.

Figure 2 shows half of a hysteresis diagram obtained by shearing very slightly a diagram obtained by Mr. J. Coulson and me from a column of untreated particles 50 centimeters long and 1 centimeter in diameter, which weighed just over 100 grams. This diagram has all the characteristics of the many others for which I have the materials.

As the figure shows, $B$ was almost exactly 2100 for an exciting field of 255 gausses, and this corresponds to a value for $I$ of only about 147. When the external field was removed, the remanent value of $I$ was about 20.8; the coercive force, however, was comparatively large, being about 16. It is evident that the exciting field would need to be very strong to magnetize the column of particles approximately to saturation. The subject of the saturization of masses of iron filings has been discussed at length by Maurain and by Trenkle.

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[2] Ewing, The Philosophical Transactions; Tanakadaté, The Philosophical Magazine, 1888; Du Bois, Annalen der Physik., 1892; "The Magnetic Circuit," chapter vi. For a criticism on this process, see Trenkle, l. c.